Optical Characterization of SIS Photon Detectors toward THz Intensity Interferometry

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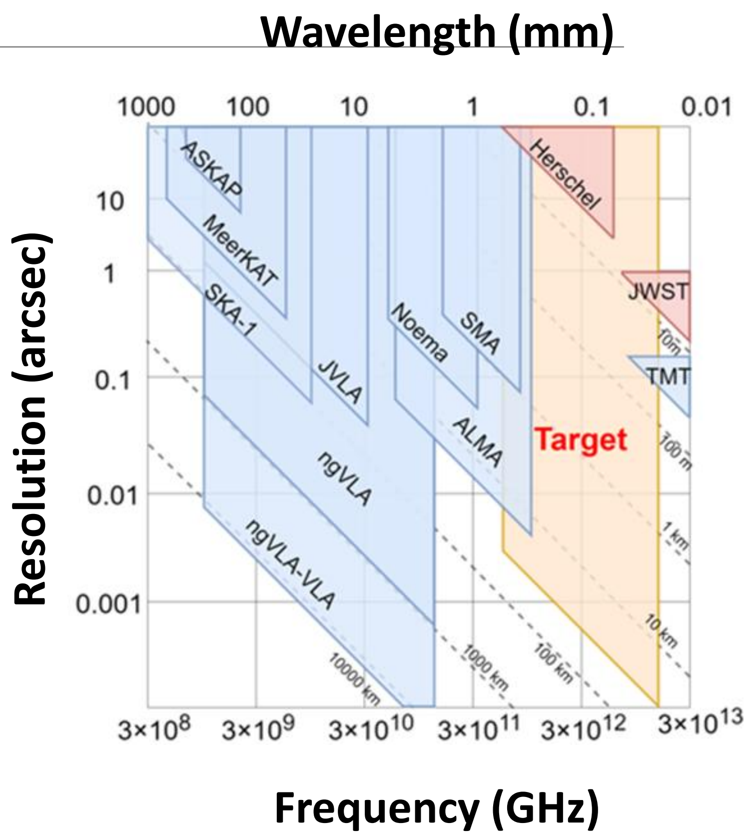
Why THz and Why Intensity Interferometry

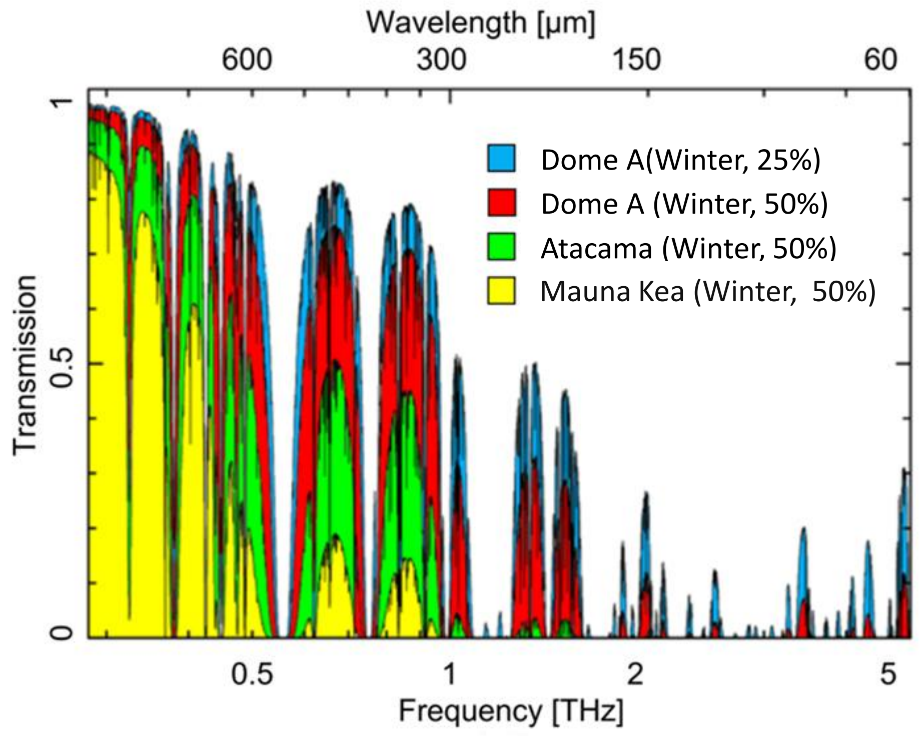
- THz band (1 – 10 THz):
  key ISM & star-formation lines
  →probes star-forming clouds & galactic evolution
- Strong atmospheric absorption and phase fluctuation
  →phase control impractical
- Intensity interferometry measures correlation of intensity fluctuations
  → robust against phase jitter & atmospheric turbulence



Frequency–Angular Resolution Parameter Space of Major Facilities
(adapted from Selina et al. 2018, Fig. 1)

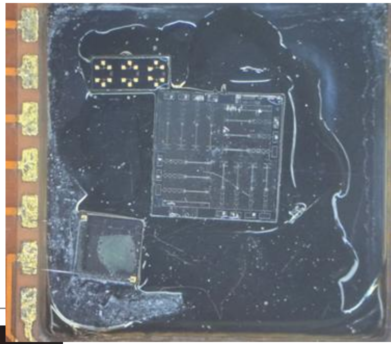
Dome Fuji Project and Our Role

- Dome Fuji Station (3810 m) — extremely cold & dry atmosphere
  → provides atmospheric windows up to several THz
- Plan: develop a 30 cm prototype THz intensity interferometer
- Goal: laboratory demonstration
  → on-site correlation measurement
- Key element: a photon detector capable of resolving ns-scale fluctuations
  → our task: characterize SIS photon detector as a candidate

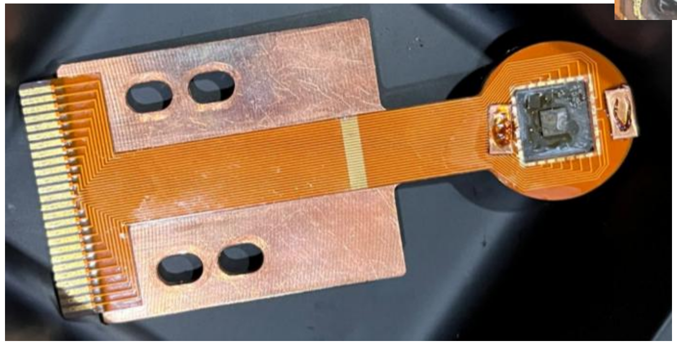


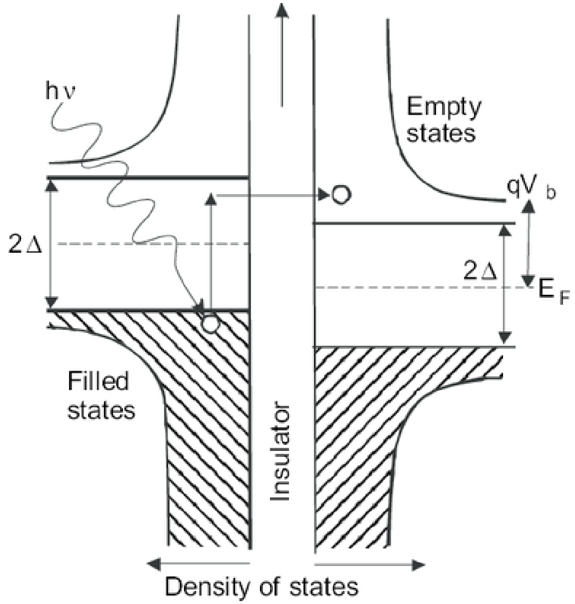
Atmospheric Transmittance at Major High-Altitude Sites
(adapted from Yang et al. 2010, Fig4)

SIS Photon Detector and Its Advantage



- SIS (Superconductor–Insulator–Superconductor) junction detects THz photons via Photon-Assisted Tunneling (PAT)
- Converts incident photon energy $h\nu$ into measurable current
- Direct detection
→ beyond heterodyne quantum noise limit
- Nb/Al/AlOx/Al/Nb junction
- Operating below ν_{gap} suppresses quasiparticle loss
→ higher efficiency



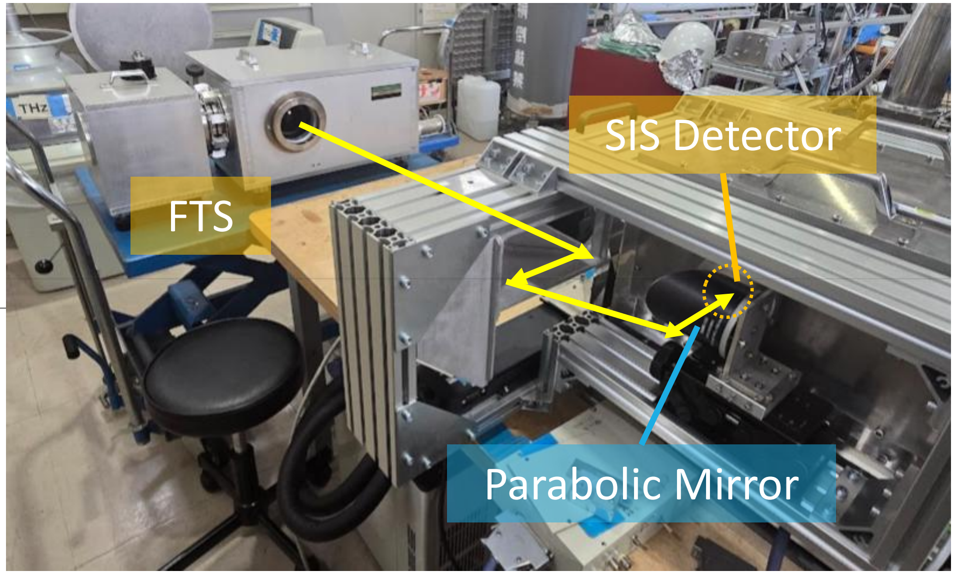


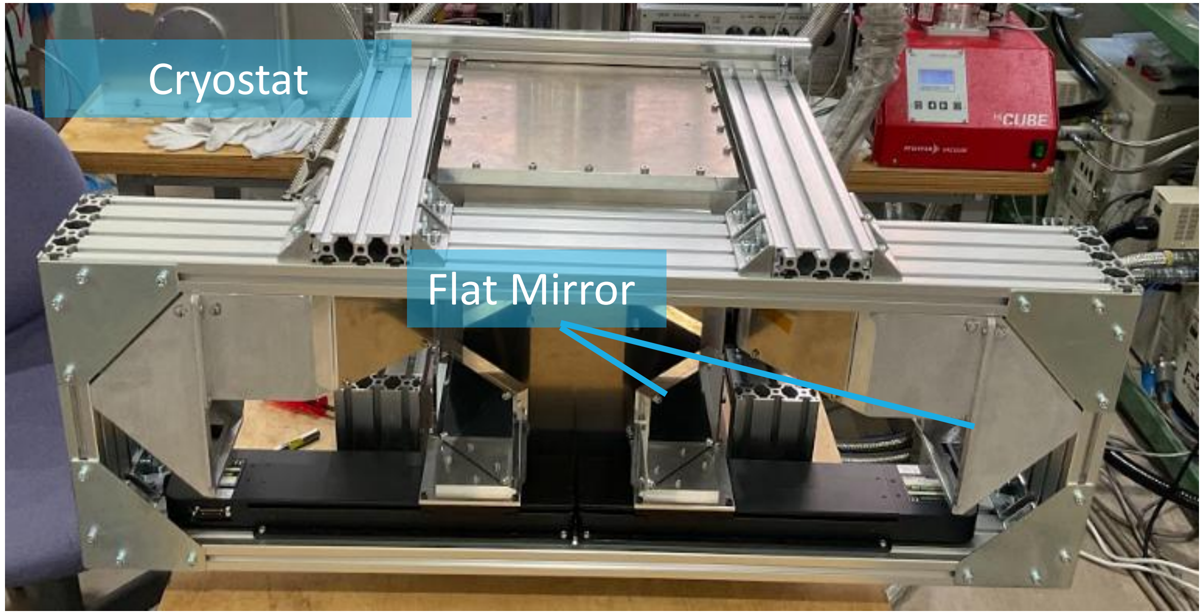
Energy Diagram of PAT in an SIS Junction
(Reproduced from Sizov 2010; after Tucker 1985)

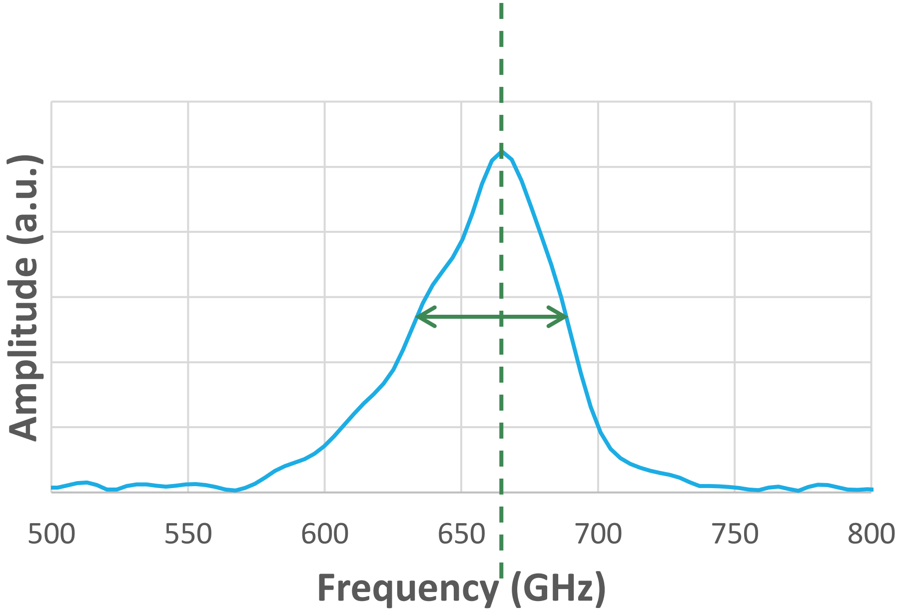
Measurement Overview

We conducted two optical tests at 0.8 K:

FTS measurement
— to determine center frequency ν_c and bandwidth $\Delta\nu$.







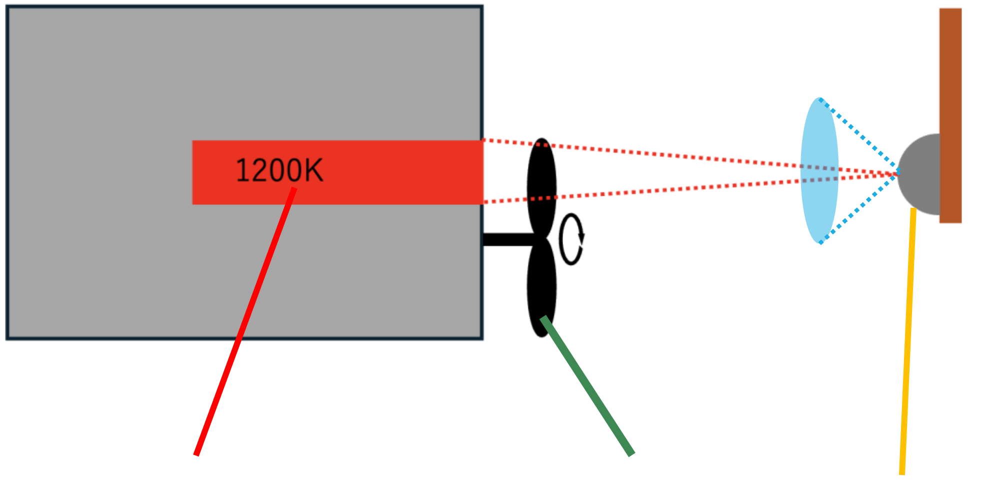
Measurement Overview

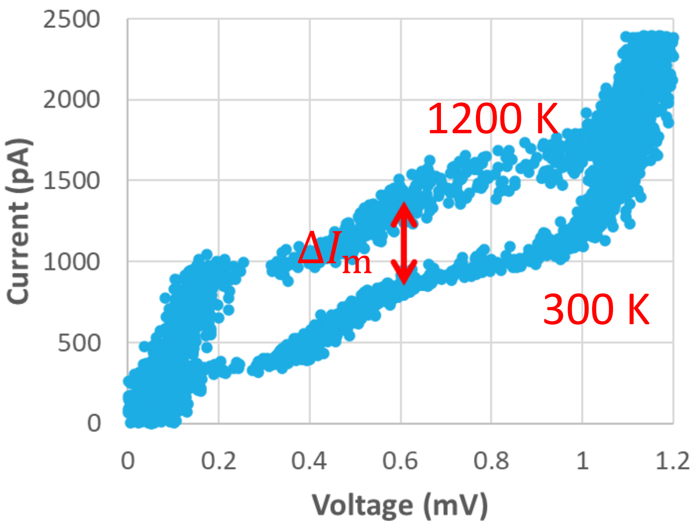
We conducted two optical tests at 0.8 K:

FTS measurement
— to determine center frequency ν_c and bandwidth $\Delta\nu$.

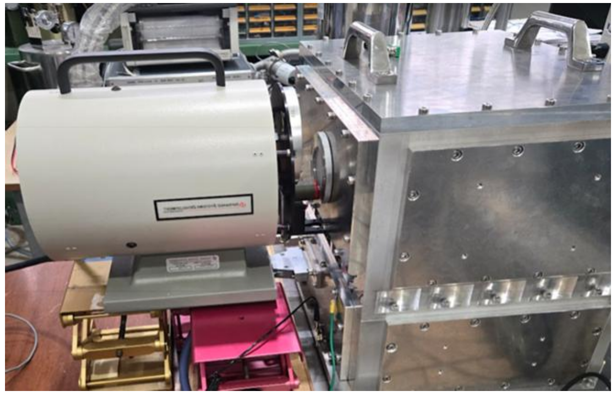
Optical efficiency measurement
— to determine η.

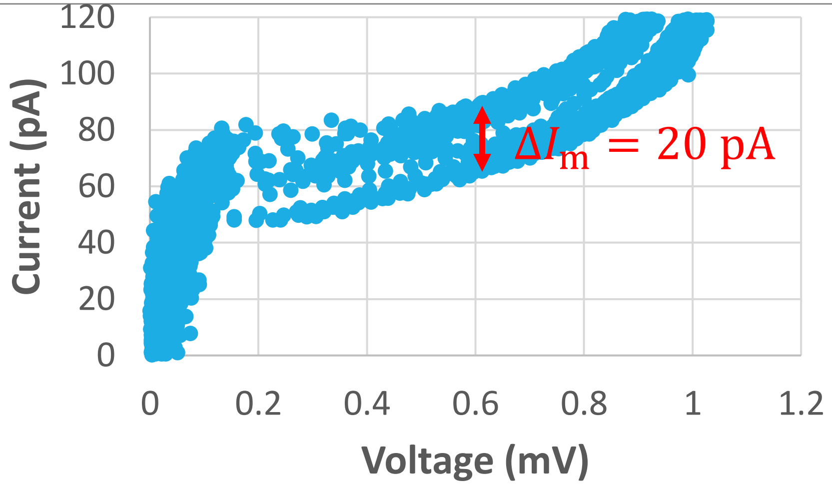
- Source: 1200 K blackbody + 300 K chopper
- Solid angle ratio $R_\Omega = 0.095$
- $\eta = \frac{\Delta I_{\mathrm{m}}}{\Delta P \cdot e/(h\nu)}$, $\Delta P = k_B \Delta T \Delta\nu R_\Omega$

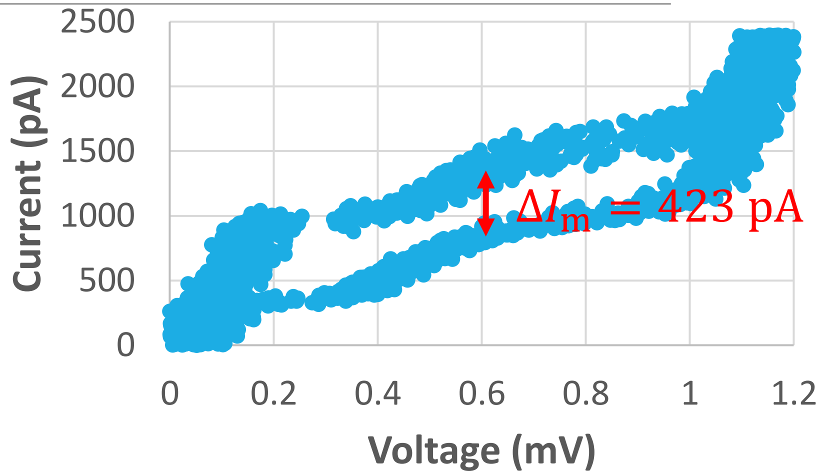


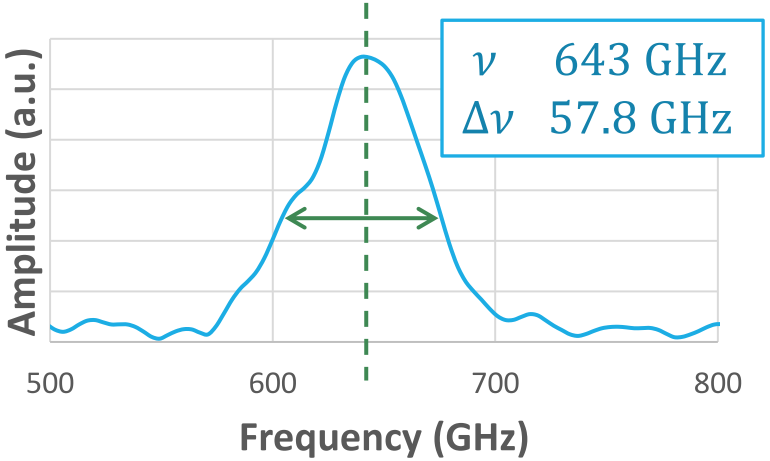


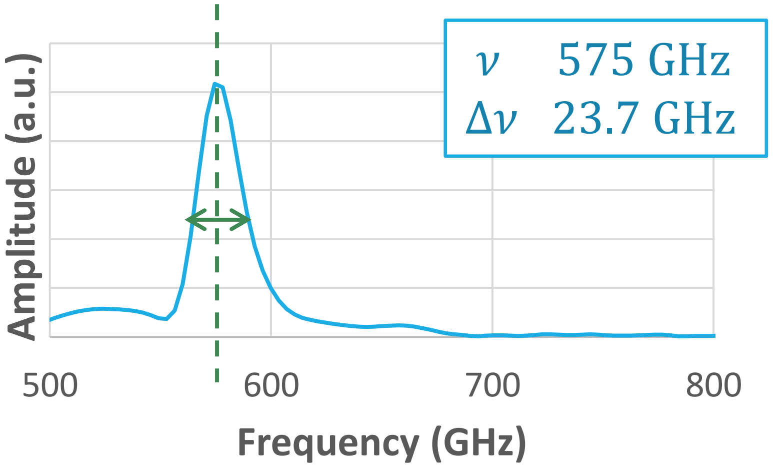
I–V and FTS Spectra (Old vs New)







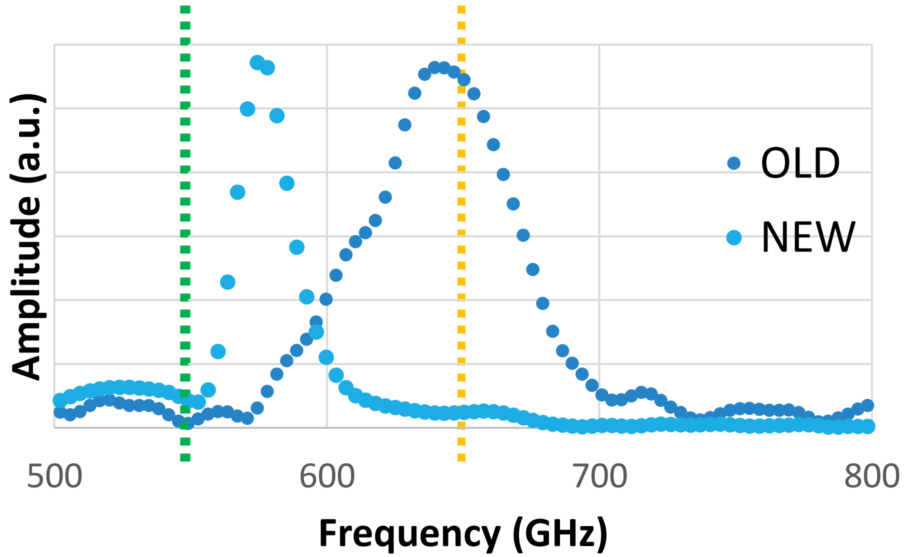




Quantitative Results

- η increased by ×46
  → improved coupling efficiency
- ν_c below Nb gap
  → reduced loss
- 575 GHz near H_2O absorption line
  → next design target ≈ 600 GHz

	ν_c (GHz)	$\Delta\nu$ (GHz)	η (%)
OLD	643	57.8	0.078
NEW	575	23.7	3.61



Implications and Future Prospects

- Optical efficiency improved from 0.078% → 3.6% (× 46)
- Current device ($\eta = 3.6\%$) is sufficient for first lab correlation experiments
- For telescope application: $\eta \gtrsim 20\%$ would be desirable
- Next steps:
  - Optimize design near 600 GHz (below gap, away from H_2O line)
  - Improve optical coupling (AR-coated Si lens, low-loss window, etc)
  - Demonstrate THz intensity correlation in lab → Dome Fuji observation

Appendix

Read-out Circuit